EVALUATION OF COATINGS APPLIED ON LESS THAN IDEAL SURFACES

AUGUST 1995

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FOREWORD

The research objective of this project was to identify coating systems that can be applied over less than “Near White Blast Cleaned" (SSPC-SP 10) steel surfaces that will perform well in a marine environment thus enabling ship forces to touch-up and maintain the corrosion control coating systems between overhauls. The research compared the performance of twenty-one coatings in various coating system combinations. Surface preparation techniques used were “Hand Tool Cleaning” (SSPC-SP 2), “Power Tool Cleaning to Bare Metal” (SSPC-SP 11), and phosphoric acid conversion coatings. "White Metal Blast Cleaning" (SSPC-SP 5) and “Near White Metal Blast Cleaning” (SSPC-SP 10) were used as the control surface preparation. Navy Formula 150 was used as the control coating.

Test environments included both simulated ballast tank immersion and marine atmospheric exposures at the NSRP’s Jacksonville, Florida test site. Fifteen systems were tested in the simulated ballast tank, and seventeen systems were tested on a marine test rack at 45° South exposure. Coating systems were evaluated at one year intervals for three years.

This report provides both the background technical information used to select candidate test materials and the results of three years of testing.

EXECUTIVE SUMMARY

Fifteen candidate ballast tank repair coating systems and seventeen atmospheric repair coating systems were evaluated over both “Hand Tool Cleaned" (SSPC-SP 2) and "Power Tool Cleaned to Bare Metal" (SSPC-SP 11) prepared carbon steel surfaces. In a limited number of cases, a phosphoric acid conversion coating was also evaluated as an alternate to surface preparation. Panels abrasive blasted to “Near White Blast Cleaning” (SSPC-SP 10) and coated with Formula 150 were used as controls. Formula 150 was also applied over the hand tool cleaned, power tool cleaned, and acid pretreated panels.

To simulate a repair condition, test panels (¼ inch thick A-36 steel) were abrasive blast cleaned followed by an application of one coat of Formula 150 to the top and bottom of each panel. The center section of each panel was left bare. The Formula 150 was applied to evaluate the performance of candidate test coating systems applied over an aged coating. The test panels were then conditioned by both immersion and atmospheric exposure for sixty days which allowed controlled rusting of the bare center portion and aging of the coated portions of each panel.

Following conditioning and application of candidate coating systems and controls, the test panels were exposed for a period of three years in two different test environments-simulated ballast tanks and atmospheric. The simulated tanks were ballasted (20 days) and deballasted (10 days) on a thirty day cycle using actual sea water. The atmospheric marine testing consisted of 45° South exposure at NSRP's Jacksonville, Florida exposure site.

In the ballast tank test environment, three proprietary products plus the Formula 150 controls had excellant performance when applied over each of the less than ideal surface (alternate) preparations. The Formula 150 also performed well when applied over the phosphoric acid treated panels. The best performing proprietary products were amine adduct, novolac, and rust/moisture

tolerant epoxies. Five of the remaining eleven coatings failed over both alternate surface preparations and six failed over one of the alternate surface preparations. Generically, the repair products based upon moisture cured polyurethanes demonstrated poor performance in immersion, as may have been predicted, but some did demonstrate acceptable performance in marine atmospheric exposure.

The importance of dry film **Coating thickness on immersion** performance was exemplified by the fact that the best performing repair coatings had applied thicknesses in excess of twelve roils.

In a significant number of cases, the Formulae 150 controls panels demonstrated poor performance in the aged overcoat areas (top and bottom) when top coated with an additional coat of Formula 150. It should be noted that, in subsequent discussions with knowledgeable Navy Paint Specialist, poor performance of two coats of Formula 150 without a topcoat of Formula 151 should be expected.

Eight of the candidate repair materials performed well in atmospheric exposure regardless of the type of surface preparation used. These included the following: water borne acrylic epoxy, waterborne epoxy, amine adduct epoxy, moisture tolerant epoxy, moisture cure zinc rich polyurethane, moisture cure polyurethane tar, zinc rich polyamide epoxy, and rust/moisture tolerant epoxy.

Waterborne epoxy and waterborne acrylic epoxy systems were included in the atmospheric portion of the program. These products are attractive choices because of reduced Volatile Organic Compound (VOC) content. The waterborne epoxies, even though having good performance over tool cleaned surfaces, did not perform well over the phosphoric acid treated surfaces. This is not surprising given water borne products sensitivity to changes in pH.

One oil and moisture tolerant epoxy performed well when applied over a damp and oily surface in atmospheric service. Another epoxy designed for oil tolerance only failed. The rust was not removed from either panel prior to oil contamination. The oil and moisture tolerant epoxy may be a viable candidate repair material for shipboard coating repair in machine and engine spaces where effective decreasing and drying is a problem.

A single panel in each series of two moisture cured micaceous iron oxide (SSPC-SP 11) systems and **one moisture cured aluminum** polyurethane system (SSPC-SP 2) failed with the remainder of the moisture cured polyurethane panels passing. Low dry film thickness may have contributed to the failures; the dry film thickness were 6.2 roils and 4.9 roils respectively. Flake pigment did not appear to improve performance.

The coating systems applied over hand wire brush cleaned surfaces performed better than the same coating systems applied over power tool cleaned surfaces. This finding is supported by the fact that five systems, including the Formula 150 controls, applied over the SSPC-SP 11 prepared surfaces failed; whereas, the same systems applied over the SSPC-SP 2 prepared surfaces had no failures. This would be unexpected by most investigators; since, the SSPC-SP 11 condition is considered as a better degree of surface preparation.

In summary, this study identified coating systems that should give reasonably good corrosion protection between overhauls when applied over either hand or power tooled cleaned surfaces prepared by ship personnel. Three additional points were also reinforced:

- Power tools should either leave a residual profile from the original blast cleaning or create a more prominent profile.

- The repair primer should be vigorously brushed into the prepared surface with a short bristle brush. Top coats may be applied with a long nap roller. Repair material should overlap the adjacent coating after sanding to a feather edge.

- The minimum dry film thickness should be 10 roils

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1.0 TECHNICAL BACKGROUND

Abrasive blast cleaning is generally considered the most cost effective method to prepare surfaces for the application of protective coatings and linings, based upon the required criteria of level or degree of cleanliness to be obtained, productivity, and cost. Unfortunately, this process generates high levels of fine dust and abrasive particles which are propelled by ricochet at surprising force and distance. The debris generated is damaging to sensitive machinery, electrical, and electronic hardware, such as limit switches, actuators, bearing surfaces, etc. The large volume of debris generated, which may be toxic, is difficult to collect and remove from ship spaces. Disposal can also be a problem.

High performance marine coatings systems have historically required a high degree of surface cleanliness, normally Steel Structures Painting Council's "Near White Blast Cleaning," SSPC-SP 10, to perform as designed. Where abrasive blasting is restricted, alternate surface preparation methods, i.e., hand and power tool cleaning, cannot achieve this required level of cleanliness. Reduced cleanliness results in the potential for degradation of performance and reduced durability of high performance corrosion control coating systems. However, these alternate cleaning processes, with their inherent levels of reduced cleanliness, are the best current technology available where abrasive blasting cannot be utilized.

For U.S. Naval vessels, the increased time interval between scheduled drydockings and maintenance has increased the demand for shipboard maintenance of anticorrosive coating systems by the ship’s work force. These demands have accelerated the need for improved power tool cleaning methods and the development of coatings tolerant of reduced cleaning levels.

The value of power tool cleaning as an alternative Surface preparation method is becoming recognized and accepted as evidenced by the following documents:

- NAVSEA F9040-AA-O10/FMA, Handbook of Shipboard Facilities Maintenance which provides comprehensive guidelines for the use of power tools for surface preparation prior to painting.

- Steel Structures Painting Council Surface preparation Standard SSPC-SP 11, "Power Tool Cleaning to Bare Metal," which defines the requirements to provide a bare metal surface and to retain or to produce an anchor profile.

This same challenge of reducing the level of surface preparation without degrading performance also exists in other areas of industrial coatings such as chemical plants. To overcome this apparent disparity between levels of cleanliness and coating performance, many new coating products are being formulated to accommodate reduced cleaning levels.

Investigators have found that the performance of coatings over power tool cleaned steel surfaces is dependent upon: the applied coating system, the availability of a surface profile, residual soluble salts remaining and the severity of the exposure environment(5,7,12,13).

Considerable development and research has been performed to validate the performance of new coating materials over substandard surface preparation. Evaluations by the National Shipbuilding Research Program (NSRP) and the Federal Highway Administration (FHWA) in the early 1980’s identified some promising candidate materials for application to compromised surfaces. Recently, David Taylor Research Laboratory-Annapolis and Ocean City Research Corporation (1), have also performed research in this area.

Numerous articles have been published postulating the characteristics that a surface tolerant coating should possess. Mr. R. S. Hullcoop(2) of the Printmakers Association of Great Britain states that, 'Ironically, oil based paints are tolerant under most conditions. . . but do not perform well under conditions of water immersion or direct chemical attack.11 Linseed oil and alkyds modified with linseed oil pigmented with either red lead or iron oxide were among some of the original SSPC Paint Specifications. These systems have a history of successful performance. It is a well known fact among coating formulators that adding boiled linseed oil to an alkyd enamel will significantly improve tolerance to a rusty surface. But as stated by Mr. Hullcoop these materials have poor resistance to water immersion and chemicals. Unfortunately, the lead and chromate anticorrosive pigments contained in many of the older formulations are classified as toxins, and their use is not recommended.

In the August 1986 Journal of Protective Coatings and Linings, S. Frondistou-Yannas(3) discussed the theoretical mechanisms by which different generic surface tolerant coatings may provide enhanced corrosion protection over compromised surfaces. Mechanisms discussed included, wetting/impregnation of the oxides, reduction of the more oxidized ferrous or ferric states to magnetite, and the stabilization of soluble salts to reduce their capability to form electrolytes.

The author also reported the results of a Federal Highway Administration (FHWA) sponsored research in which an oil modified red lead pigmented alkyd was used as a control. Tar mastic, tannic acid treatment with urethane topcoat, epoxy mastic, aliphatic and moisture cured polyurethanes, waxes, and greases were tested in both an accelerated weathering environment and a two year field exposure.

The following conclusions were made:

. None of the test coatings are expected to provide long term protection (five years or more) in the field test environments.

. The tar-mastic performed best of the candidate materials.

. Chemically cured epoxy and urethane systems produced significant blistering and sample undercutting.

Frondistou-Yannas, Soltz, Thomas, Appleman, Boocock, Weaver, Peart, and Fultz(3,5,7,8) have discussed the effects of soluble salt contamination of steel substrates on the performance of protective coatings. Corrosion products being formed occlude and trap soluble salts that are common with the exposure environment. In a marine environment sea salts are the major contaminant with chlorides being the dominant concern. These salts must be removed from the steel substrate before coating application or coating performance and durability are compromised: unless, the coating is specifically formulated to be tolerant to these contaminants. Unfortunately, truly tolerant materials have yet to be identified.

M. Marcel, et al([4]) reported the results of a test program in which all coatings tested (oil/alkyd, alkyd, chlorinated rubber, vinyl, polyurethane, epoxy/polyurethane, zincsilicate/chlorinated rubber, zinc silicate, and zinc silicate/vinyl) failed within three to five years except for the systems that incorporated a zinc silicate primer. This same report also states that, in general, accelerated coating deterioration was initiated when substrate chloride levels reached 500 milligrams per square meter in atmospheric exposure. Some systems such as polyurethane and chlorinated rubber were more chloride salt sensitive with failures initiating at 100 milligrams per square meter concentrations. Using a pressurized salt water immersion test, Soltz([5]) in a NSRP study found that the chloride coating failure threshold level as low as 50-100 milligrams per square meter immersion service for barrier type marine tank coatings. FHWA sponsored research(’) concurred that the zinc silicates were much less sensitive to salts than barrier organic type coatings.

Noreen Thomas(6) wrote an article which summarizes the mechanisms by which various generic surface tolerant coatings work and discusses tolerances for soluble salt contamination. The conclusion of this article is that "the best performance on rusty steel substrates can be divided into two types: barrier systems and red lead, oil based primers." Solvent borne epoxy mastics were reported to give the best performance, which was attributed to barrier properties.

An unpublished reference suggests that a coating formulated to be applied over residual iron oxides may not perform as well over abrasive blasted surfaces from which the oxides have been removed. One theory proposes that if a material is formulated to convert the rust to a more stable oxide and no oxide is available for the reaction to occur, the un-reacted residue may remain on the surface and have a detrimental effect on the performance of the subsequently applied coating. Likewise, a coating designed to be dependent on wetting out the surface rust to facilitate adhesion may not have the necessary internal strength to remain attached to a clean surface.

Coating producers report that coatings have been developed to wet out rust using polar resins, to displace water, or to be compatible with oil by absorbing oil into the coating formulation where the oil acts as a plasticizer. Other materials such as some polyurethane require moisture as a reactant to cure. These materials may react with the water of hydration contained in the iron oxides to provide improved coating adhesion. Conversion treatments, consisting of tannic, phosphoric, or other acids with or without resin modifiers may react to form more stable iron complexes with the corrosion products. Vinyl wash primer, MIL-P-

15328, is an example of this type of product being a resin modified phosphoric acid with a zinc chromate anti-corrosive pigment.

Another approach reported to improve coating performance is to add a flake pigment to the coating. Theoretically, the flakes orient parallel to the surface and increase the water ingress path of the barrier coating, thus improving resistance to liquid permeability. However, Dr. Hendry(14) reports that as more micaceous iron oxide, a laminar pigment, is added to the paint formulation, the pigment volume concentration increases, and the moisture permeability increases allowing water to more easily enter and leave the paint film/steel substrate interface. This improves paint film blister resistance. Some of the formulations selected for the test program contained either aluminum r 91ass, or micaceous iron oxide pigments which are laminar in shape.

2.0 TESTING

The NSRP Ship production Committee, Surface Preparation and Coatings SP3 Panel recognizing the vital need for repair coating systems that would perform well over hand and power tool prepared surfaces, initiated this research effort to determine the current state-of-the-art.

A literature review was performed and suppliers contacted for performance data on commercially available surface tolerant coating systems that might provide reasonable anticorrosive protection when applied to a less than SSPC-SP 10, "Near White Blast Cleaning" substrate.

Marine atmosphere and salt water immersion test environments were selected to evaluate the candidate materials. Early in the program a decision was made that laboratory testing was not the best protocol to use; because in many cases, the candidate materials had already undergone similar laboratory screening. The actual service exposure conditions which were selected, also introduces the less known phenomenon of biological attack which may contribute to the degradation of corrosion control coatings in marine applications.

The objective of the study was to evaluate the performance of the candidate materials as marine repair coatings. As such, the coatings had to be acceptable for application over less than ideal surfaces and be compatible with the existing shipboard coating systems and exposure environments.

Table 1 contains a list of the candidate materials selected for comparison testing. The candidate materials were selected in an attempt to evaluate and validate many of the theoretical mechanisms for improving coating performance over compromised surfaces, as discussed in Section 1.0 of the Technical Background.

TABLE 1
TEST MATERIALS

MANUFACTURER	PRODUCT DESIGNATION	DESCRIPTION	Voc LB/GALM
AMERON	AMERGUARD 149	WATERBORNE EPOXY PRIMER	NONE
AMERON	AMERCOAT 738	INORGANIC COATING	0.8
AMERON	AMERCOAT 385P	POLYAMIDE EPOXY	2.3
AMERON	AHERCOAT 385	POLYAMIDE EPOXY	2.3
AMERON	AMERCOAT 2203	WATERBORNE ACRYLIC EPOXY FINISH	NONE
AMERON	AMERCOAT 3207	WATERBORNE ACRYLIC EPOXY PRIMER	1.9
CARBOLINE	CARBOLINE 858	POLYAHIDE EPOXY ZINC RICH	2.5
CARBOLINE	CARBOLINE 890	POLYAHIDE SURFACE TOLERANT EPOXY	1.8
CORROLESS NORTH AMERICA	CORROGUARD EP	RUST AND MOISTURE TOLERANT EPOXY	*
ORROLESS NORTH AMERICA	CORROLESS SHB	MOISTURE CURE POLYURETHANE PRIMER	●*
DEVOE	BAR RUST 236	POLYAMIDE SURFACE TOLERANT EPOXY	1.4
DEVOE	CONTROL	FORMULA 150, TYPE 1, HIL-P-24441	3.0
INTERNATIONAL	INTERGUARD FPA327	AMINE ADDUCT SURFACE TOLERANT EPOXY	N/A
INTERNATIONAL	INTERTUF KHA062	AMINE NE ADDUCT SURFACE TOLERANT EPOXY	2.7
HILES (HOBAY)	FORMULA 2225	MOISTURE CURE POLYURETHANE ALUMINUM	N/A
HILES (HOBAY)	FORMULA 291-39	HOISTURE CURE POLYURETHANE TOPCOAT	NIA
NSP SPECIALTY PRPDUCTS	NSP 120	NOVOLAC SURFACE TOLERANT EPOXY	NONE
VALSPAR	VEPOK 500AL	01 L TOLERANT EPOXY	2.9
VALSPAR	VALSPAR 600	HOISTURE TOLERANT EPOXY	3.5
VASSER	HC-HIOWASTIC	HOUSTURE CURE Hicaceous IRON URETHANE	2.6
WASSER	UC-TAR	HOISTURE CURE TAR MODIFIED URETHANE	2.8
UASSER	HC-ZINC	HOf STURE CURE ZINC POLYURETHANE	2.8

VOTES: N/A IS NOT AVAILABLE

● Uni ted Kingdom product. Volune sol ids reported as 96%

● **United Kingdom prodcut.volume solids reportVolww solids reported as 49%

A36 carbon steel was selected as the test substrate. The test panels were fabricated from a single plate of one-quarter inch thick, new hot rolled steel plate with intact mil scale. This reduced the possibility of introducing test variables because of differences in steel conditions/composition. Duplicate six inch by eighteen inch panels were used for atmospheric exposure testing. Single six inch by nine inch panels were prepared for salt water immersion because of the limited test tank space.

Test panels were initially abrasive blast to "White Metal Blast Cleaning,"SSPC-SP **5. A** six to eight mil dry film thick coat of Epoxy, Mil-P-24441, Type I, Formula 150 was then applied to each panel with the exception of an area in the center of each panel which was left bare. The bare area on the atmospheric panels were six inches by six inches and on the immersion panels, three inches by six inches. The cured coated panels were then placed in salt water immersion for thirty days. After thirty days the atmospheric panels were removed and conditioning continued on an exterior exposure rack at the Jacksonville, Florida test site for another thirty days. The panels designated for immersion were exposed to salt water immersion for an additional thirty days. In all, the sea water immersion panels were allowed to corrode for sixty days under immersion conditions and the exterior panels for thirty days each in immersion and exterior atmospheric exposure. Formula 150 was selected both as the coating to be repaired and as a control repair coating. Having been used extensively in the United States marine industry, formula 150 is a known formulation with a documented performance history.

Two surface preparation repair techniques were selected, "Hand Tool Cleaning" to SSPC-SP 2 and "Power Tool Cleaning to Bare Metal,Jl to **SSPC-SP 11.** This represents both extremes of hand tool cleaning methods. It should be noted that the rust on the panels which were initially exposed to salt water and then placed on the test fence to complete the conditioning were more tightly adhered and more difficult to remove than the rust on the panels which were only conditioned in salt water. Abrasive blast cleaning to SSPC-SP 10, "Near White Blast Cleaning" was chosen as the control surface preparation for aged and conditioned panels. Also a set of "White Metal Blast Cleaned," SSPC-SP 5, panels were coated with Formula 150. These panels were not conditioned and repaired but were exposed with the balance of the panels during the testing phase as an additional control. In this manner controls were made for both the surface preparation techniques and a coating system.

No attempt was made to remove soluble salt contamination with water from the bare repair area prior to or after surface preparation. The conditioned panels had a heavy rust deposit with a high concentration of salt. (Figure 1).

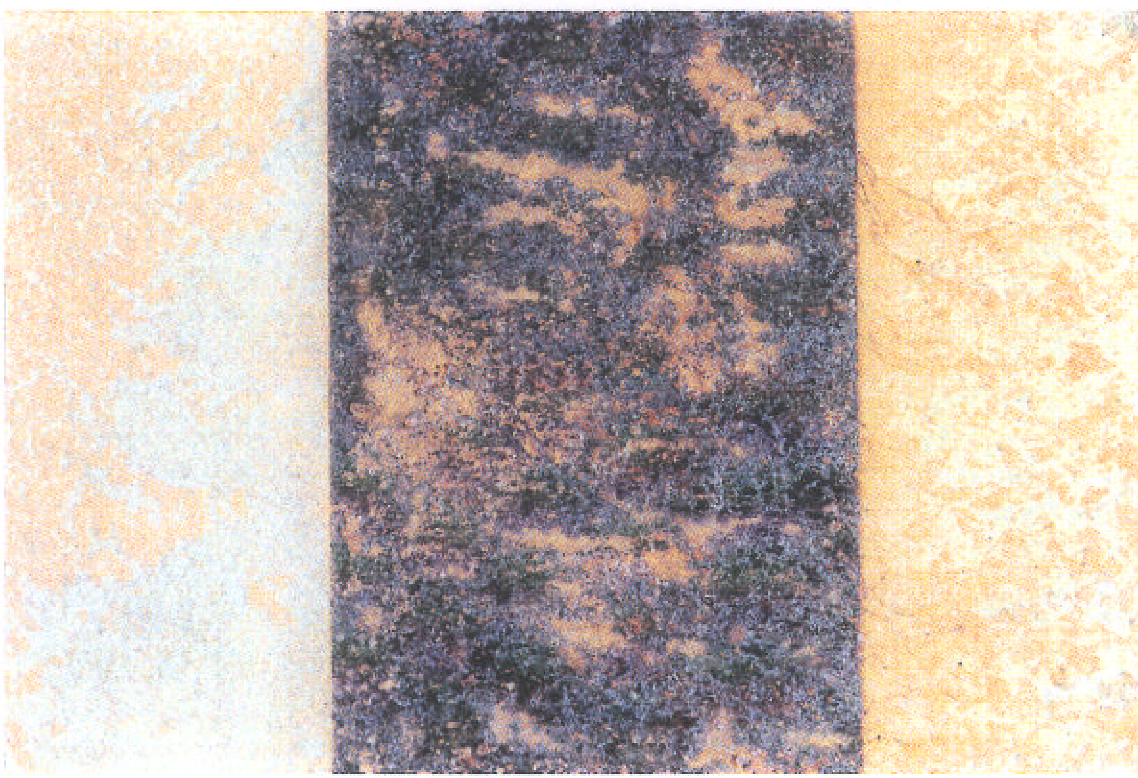

FIGURE 1: CONDITIONED STEEL PANELS BEFORE SURFACE PREPARATION

The surface preparation procedure began with hand wire brushing the entire panel to remove the heavy rust stain from the initially applied control coating. Secondly, the bare corroded center section of each panel was prepared using one of the selected surface preparation methods, SSPC-SP 2 or SSPC-SP 11. A hand steel wire brush was used for SSPC-SP 2, and a coarse composition 3M wheel was used for SSPC-SP 11. The profile for the power tooled cleaned panels was not reestablished since these panels were originally abrasive blasted and had a residual profile. The measured residual profile after cleaning was 0.9 to 1.2 mils.

FIGURE 2: POWER TOOLED CLEANED PANEL PROFILE MEASUREMENT

Following hand or power tool cleaning, the intact Mare Island Epoxy Formula 150 was feather edged approximately one inch using 40 grit sand paper. The balance of the panel was not sanded. The last step consisted of solvent wiping the entire panel to remove loose contaminants and oils from the panels (Figures 3 and 4).

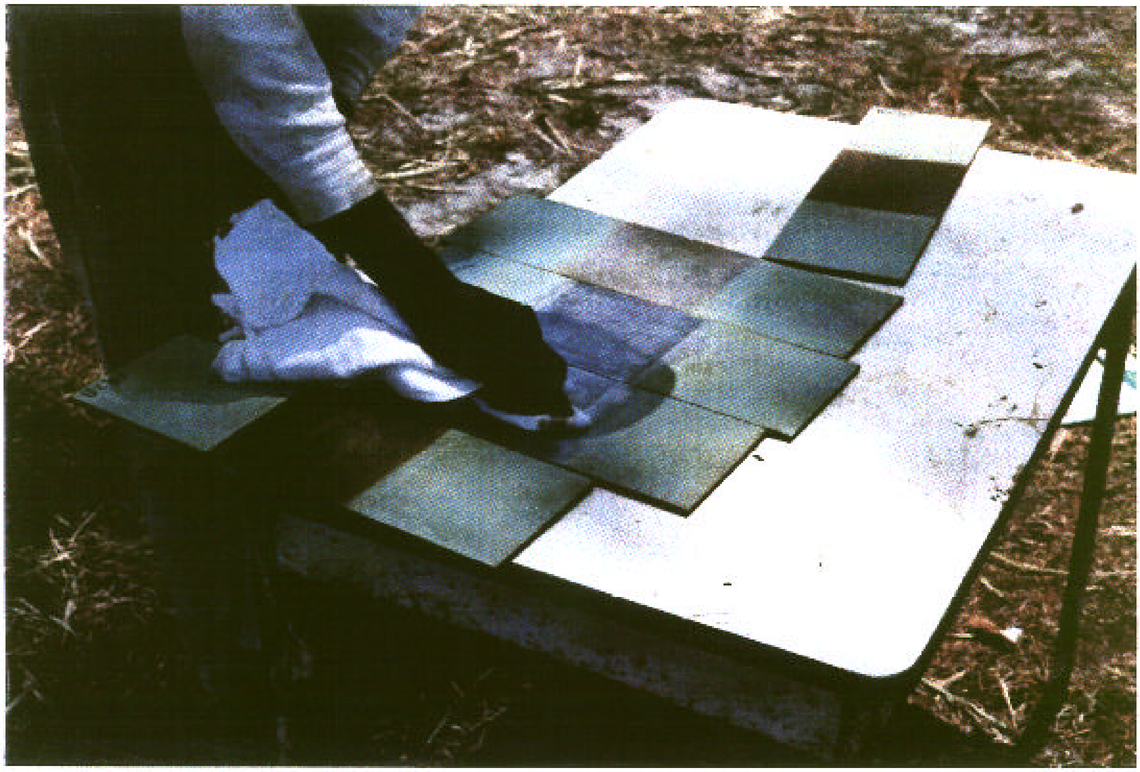

FIGURE 3: SOLVENT WIPING AS THE LAST STEP

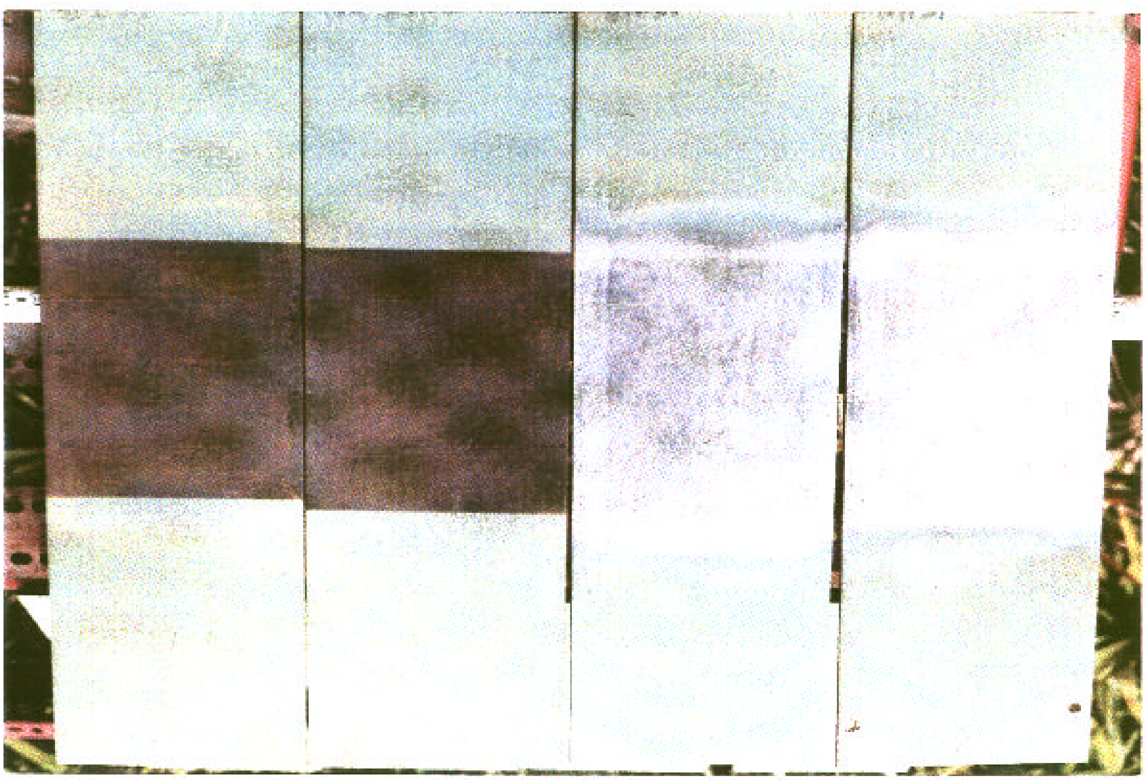

FIGURE 4: PANELS AFTER HAND AND POWER TOOL CLEANING

After completion of surface preparation steps, the surface of two panels from each surface preparation group was analyzed for soluble salt content. The SSPC technique of sample collection and analysis was used (Figure 5). Table 2 contains the results of the test.

FIGURE 5: PERFORMING SOLUBLE SALT TEST

TABLE 2-TEST PANEL CHLORIDE CONTAMINATION LEVELS

PANEL TYPE	SURFACE PREPARATION	SAMPLE A LEVEL MILLIGRAMS/M^2	SAMPLE B LEVEL MILLIGRAMS/M^2	AVERAGE LEVEL MILLIGRAMS/M^2
ATMOSPHERIC	NONE	43	32	38
IMMERSION	NONE	194	183	189
ATMOSPHERIC	SSPC-SP 2	22	22	22
IMMERSION	SSPC-SP 2	108	86	97
ATMOSPHERIC	SSPC-SP 11	43	38	41
IMMERSION	SSPC-SP 11	140	108	124

As can be seen from the tabulated results there is more remaining salt on the power tool cleaned SSPC-SP 11 panels than the hand tool cleaned SSPC-SP 2 panels. The swab test technique used which is described in detail in FHWA Publication FHWA-RD-91-001[7].

The first coat of the repair coating was then applied and worked into the cleaned and feathered area using a bristle brush.

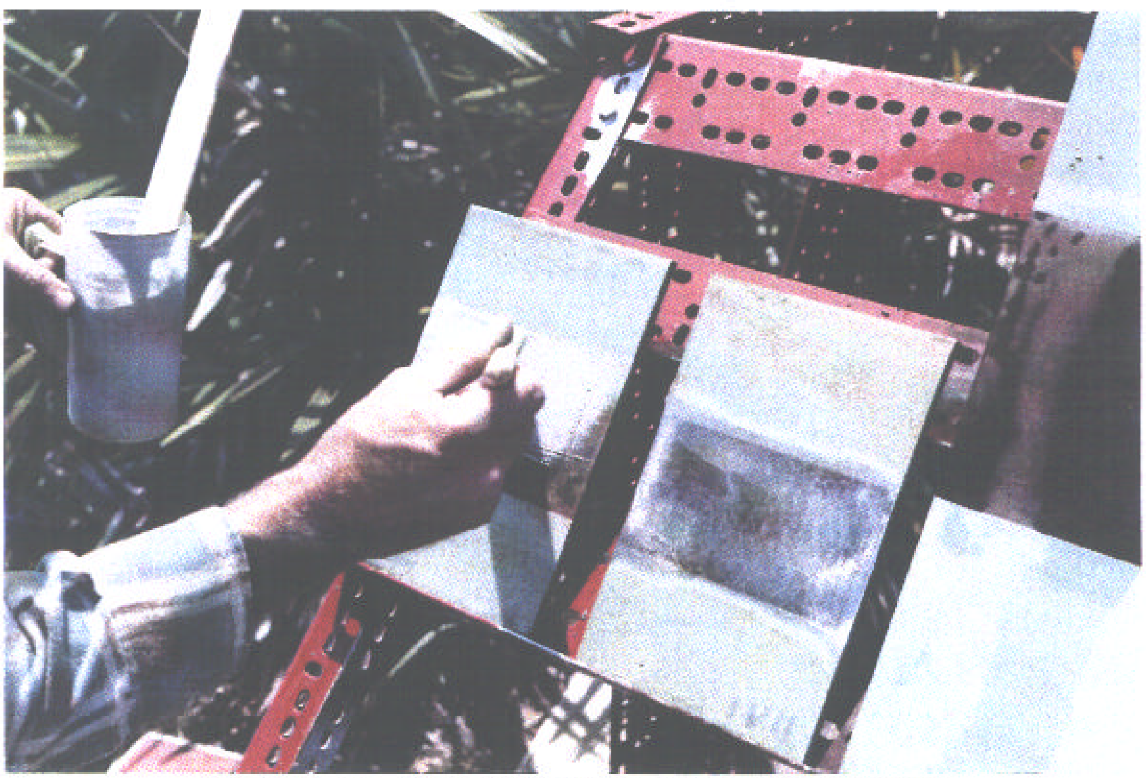

FIGURE 6: APPLICATION OF THE FIRST COAT

After over night cure, a second coat was applied over both the first repair coat and the preexisting Formula 150 using a roller (Figure 7). Each coating material was applied un-thinned at the packaged viscosity. The edges of the panels were coated with coal tar epoxy and were not included in the condition grading. The panels were allowed to cure for seven days prior to exposure.

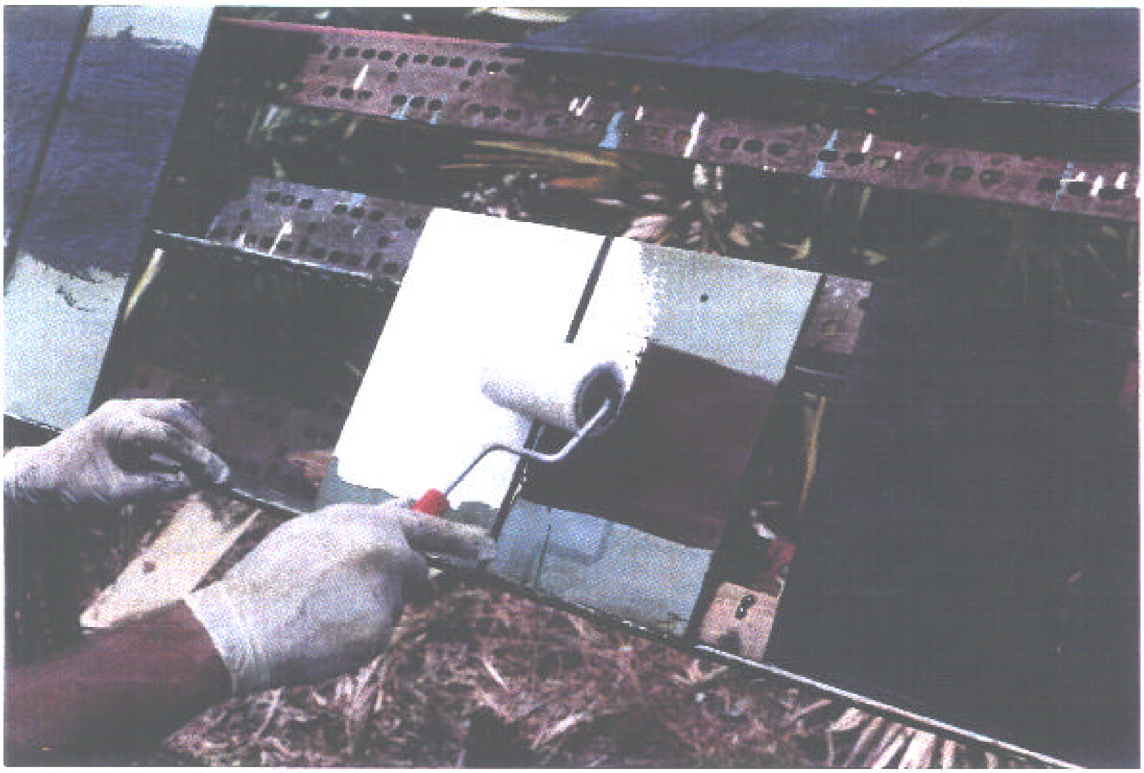

FIGURE 7: APPLICATION OF FINISH COAT

A limited number of coatings were also applied over rust conditioned panels after treatment with a gelatinous phosphoric acid product (Figure 8). In one case, this conversion treatment was applied directly to the conditioned rust (Figure 9) and on other panels after cleaning by hand wire brushing to SSPC-SP 2 or power tool cleaned to SSPC-SP 11. Each treated panel was allowed to dry and then rinsed with water to remove any un-reacted acid.

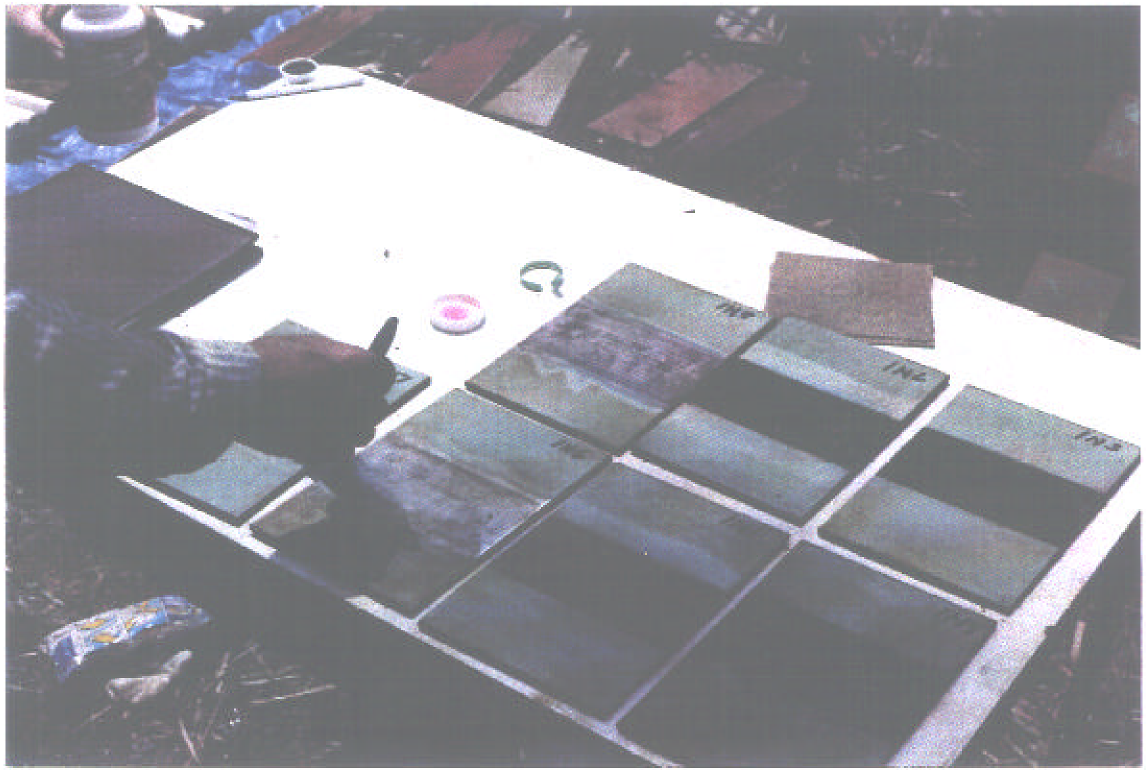

FIGURE 8: APPLICATION OF CONVERSION COATING

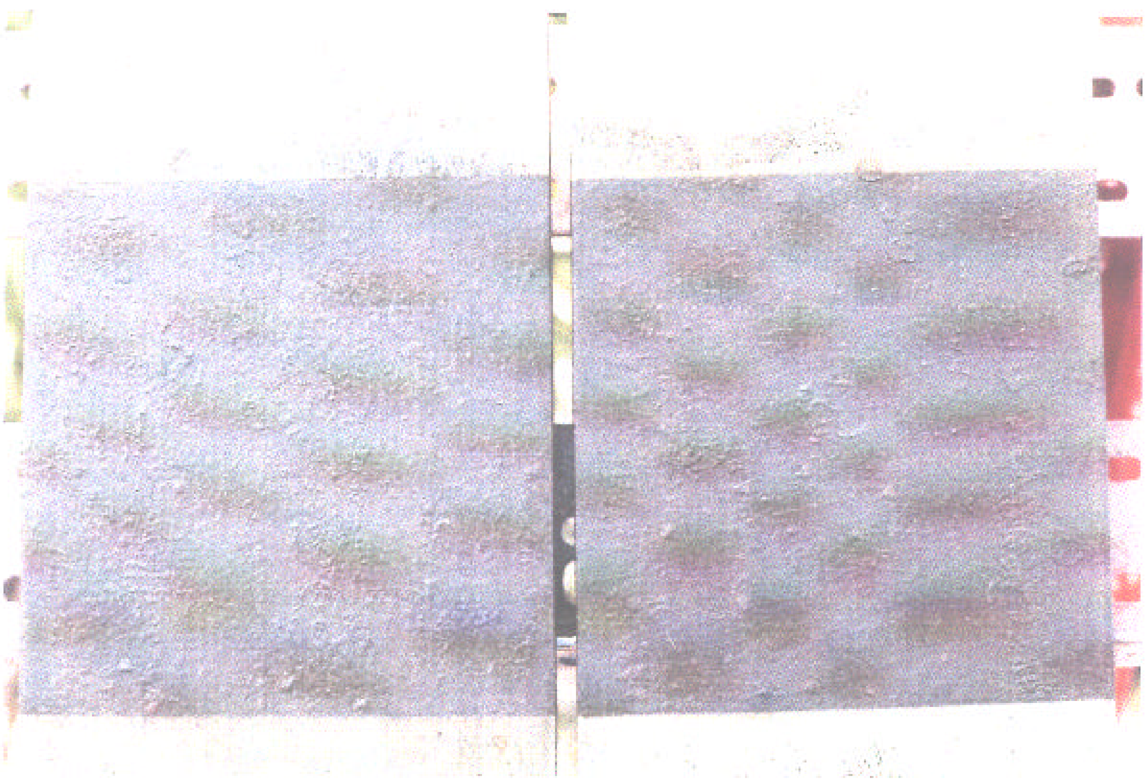

FIGURE 9: PANELS WITH NO SURFACE PREPARATION AFTER TREATMENT

Two coatings systems were applied over surfaces wet with water and/or contaminated with used diesel oil (Figure 10). The excess oil was removed by wiping with a dry rag before coating application but the surface was not solvent cleaned.

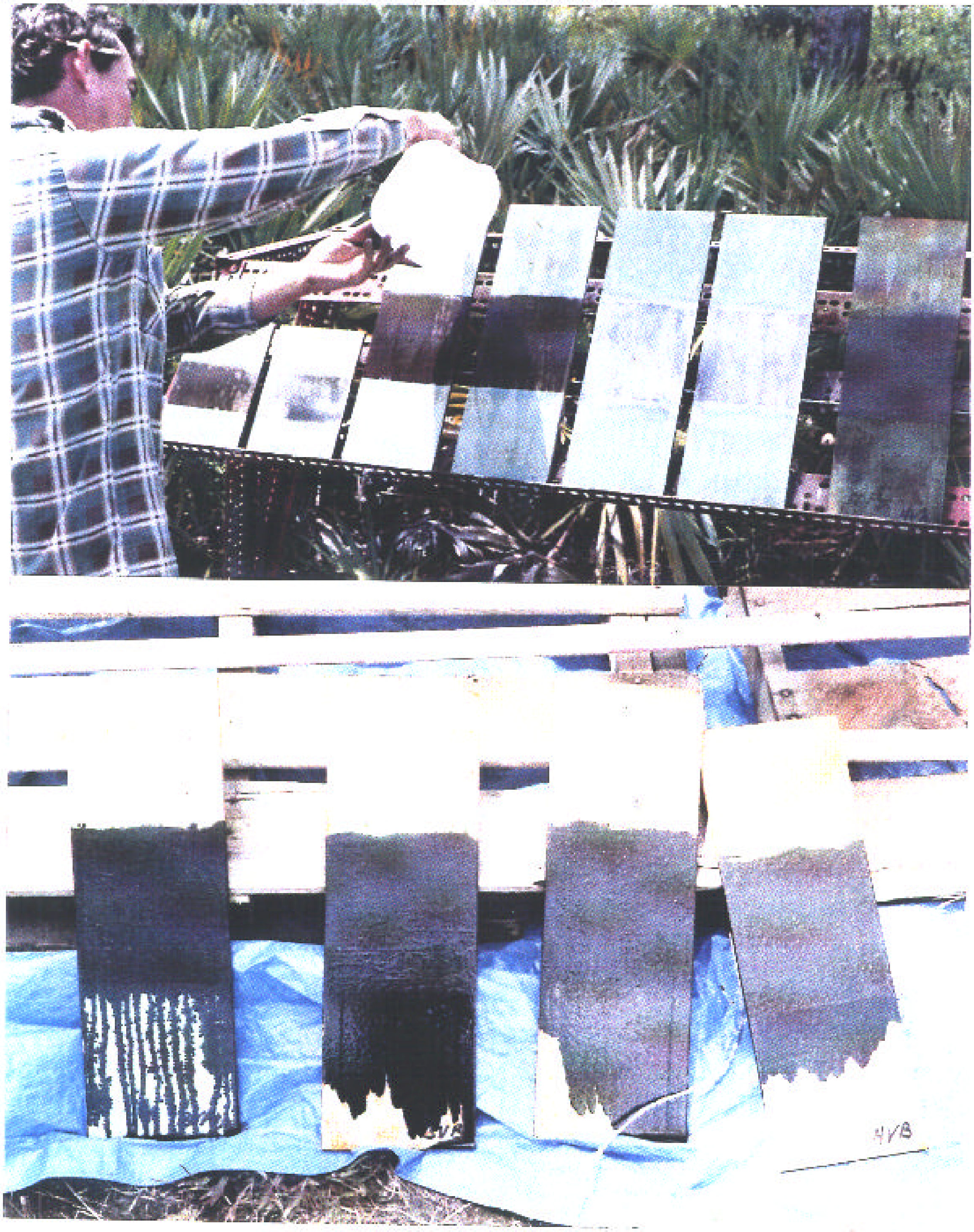

FIGURE 10: TOP-PANELS BEING WET; BOTTOM-OIL CONTAMINATION

The panels were exposed to one of two test environments. One set was placed on exterior exposure rack in a marine environment at a 45° angle facing South. A second set, the six inch by nine inch panels, were placed in a simulated ballast tank which is filled with sea water. The water was retained in the tank for twenty days. The tanks were then emptied and left to set for ten days until they were reballasted. During the empty phase some salt water remained in the tank. Even though the panels were not exposed to immersion during this period, the atmospheric condition in the closed tank was very humid. This test regimen was chosen because it closely resembles commercial ship ballast cycles.

FIGURE 11:* TEST *SITE SHOWING BALLAST TANK AND TEST FENCE

3.0 RESULTS/CONCLUSIONS

When preforming the evaluations, coating systems judged to be a rust grade seven (0.3% rust) or less per ASTM D 610/SSPC-Vis 2 and/or an undercut from the scribe of 0.25 inch or greater were considered as failures.

The test panel numbering system was derived to indicate the type of surface preparation used. The first number is the sequence number for a candidate test material, and the first letter denotes the manufacturer. The next position defines the surface preparation used. This would be either a "2" for SSPC-Sp 2 or an "ll" for **SSPC-SP 11.** The last letter is either an "A" or "B" and is only used if duplicate panels are tested. An example for atmospheric exposure would be "lA2A" were the "1" denotes the sequential number; the "A" denotes "Ameron," the "2" denotes "SSPC-SP 2," and the final "A" denotes the "A" panel in a duplicate series.

3.1.1 One Year Exposure

3.1.1.1 Atmospheric Exposure (See Table 3)

- The modified polysiloxane inorganic coating failed by delamination from the repaired substrate when applied over both SSPC-SP 2 and SSPC-SP 11 cleaned surfaces. Excessive film thickness resulting from no thinning during application could have been a factor. No delamination or failures were noted for the portion of the panels where the polysiloxane was applied over the intact Formula 150. (Panels 2G2A, 2G2B, 2G11A, and 2G11B)

- The Formula 150 control failed by delamination from the substrate when applied over **SSPC-SP 11** surface preparation (Panels lK1lA and lK1lB). The same Formula 150 applied over the SSPC-SP 2 surface prepared panels was a rust grade 10 (Panels 1K2A and 1K2B). The superior

3.1.1.1 **One Year Atmospheric (Continued)**

performance of the SSPC-SP 2 repair area as compared to the SSPC-SP 11 repair area may be unexpected by most investigators but proved to be relatively common with a significant number of candidate repair coatings after three years of atmospheric exposure.

- The oil tolerant epoxy failed by delamination from the rusted substrate which had been contaminated with diesel motor oil (Panels 3VA and 3VB), but similar panels were a rust grade 10 when the coating was applied over a combination of oil and moisture (Panels 4VA and 4VB). No failures were noted on the Formula 150 overcoated areas. This system was selected to evaluate the ability of coating to absorb oil contamination into the coating matrix without degrading performance.

- Duplicate water borne epoxy panels cleaned to SSPC-SP 2 and treated with phosphoric acid developed blisters (8F) at scribe in the repair area (Panels 1N8 and 1N9). No failure of the Formula 150 recoated area was noted. Similar panels cleaned to SSPC-SP 11 demonstrated no rusting (Rust Grade 10) in either the repaired or coated area (Panels 1N1O and lN1l). Panels with no surface preparation and treated with phosphoric acid totally failed by delamination in the repair area (1N12 and 1N13) .

3.1.1.2 Sea Water Immersion (See Table 4)

- The modified polysiloxane failed by delamination over both surface preparations (Panels 1A2 and lA1l).

- The polyamide surface tolerant epoxy panel (2B11) prepared to SSPC-SP 11 failed by delamination of the repaired area. It failed similarly on duplicate

3.1.1.2 One Year Sea Water Immersion (Continued)

atmospheric exposure SSPC-SP 11 panels (2B11A and 2B1B) by under cutting and delamination at scribe. The coating also failed when applied over the SSPC-SP 2 cleaned repair area in the test tank sea water immersion (Panel 2B2) .

. One moisture cured polyurethane tar coated panel (2w2) and the moisture cured polyurethane aluminum primer/topcoat (1F2) failed in the repair area by rusting. Both systems were hand tool cleaned to SSPC-SP 2. The repair areas had a total coating thicknesses of 8.2 and 8.4 roils respectively. The topcoated areas were a rust grade 10. The moisture cured micaceous iron oxide polyurethane overcoated with Formula 150 also failed when applied over the SSPC-SP 11 prepared panel (3W11).

3.1.2 Three Year Exposure

3.1.2.1 Atmospheric Exposure (See Table 3)

. **All** of the waterborne epoxy (Panels 1A2A, 1A2B, lA1lA, & lA1lB), water borne acrylic epoxy (Panels 2A2A, 2A2B, 2A11A, & 2A11B), zinc rich polyamide epoxy with polyamide topcoat (Panels 1B2A, 1B2B, lB1lA, & lB1lB), rust and moisture tolerant epoxy (Panels 1C2A, lC2b, lC1lA, & lC1lB), amine adduct surface tolerant epoxy (Panels 1G2A, 1G2B , lG1lA, & lG1lB), epoxy moisture tolerant (Panels 2V2A, 2V2B, 2VllA, & 2V11B), moisture cure zinc rich polyurethane (Panels 1J2A, 1J2B, lJ1lA, & lJ1lB), and moisture cured polyurethane tar primer with moisture cure polyurethane topcoat (Panels 3J2A, 3J2B, 3J11A, & 3J11B) were graded as rust grade ten and zero blisters regardless of surface preparation technique used. There were had no significant cut backs at the scribe.

3.1.2.1 Three Year Atmospheric Exposure (Continued)

- The phosphoric acid applied over the SSPC-SP 2 prepared surfaces (Panels 1N8 and 1N9) and the waterborne epoxy with phosphoric acid treatment and no surface preparation (Panels 1N12 and 1N13) failed. The acid treated SSPC-Sp 11 prepared panels with the same system were graded as rust grade 10 (Panels 1N1O and lN1l). The non-treated waterborne epoxy coated equivalents (Panels 1A2A, 1A2B, lA1lA, & lA1lB) had rust grade ratings of ten in both the repaired and overcoated areas. The phosphoric acid treated panels appears to degrade the performance of the water borne epoxy. This could be attributed to the fact that waterborne coating materials are sensitive to low pH .

- One moisture cure polyurethane panel (2C11A) prepared to SSPC-SP 11 failed. The duplicate SSPC-SP 11 prepared panel and both the SSPC-SP 2 prepared panels had rust blisters which had not ruptured (Panels 2C11B, 2C2A, & 2C2B) . These panels will probably fail within one year. One panel (1V2A) cleaned to SSPC-SP 2; primed with an aluminum pigmented moisture cured polyurethane, and topcoated with a moisture cured polyurethane topcoat failed. The second SSPC-SP 2 and both the SSPC-SP 11 prepared test specimen were grade as rust grade 8 with rust blisters visible (Panels 1V2B, lV1lA, & lV1lB) . The micaceous iron oxide moisture cured polyurethane cleaned to SSPC-SP 11 (Panel 2J11A) also failed; whereas, the duplicate panel and both the SSPC-SP 11 panels (Panels 2J2A, 2J2B; & 2J11B) were rust grade 8. The use of flake type pigments (micaceous iron oxide and aluminum) did not seem to improve the performance of the moisture cured polyurethane.

3.1.2.1 Three Year Atmospheric Exposure (Continued)

performance of these two generic materials. In both cases, regardless of surface preparation, the zinc primed panels (Epoxy-Panels 1B2A, 1B2B, lB1lA, & lB1lB) and Polyurethane-Panels 1J2A, 1J2B, lJ1lA, & IJ1lB) outperformed the straight polyamide epoxy and micaceous iron primed panels in the same series (Epoxy-2B2A, 2B2B, 2B11A, & 2B11B and polyurethane-2J2A, 2J2B, 2J11A, & 2J11B).

- Duplicate SSPC-SP 11 panels coated with two different surface tolerant polyamide epoxies (Panels 2B11A, 2B11B, lD1lA, & lD1lB) and a novolac surface tolerant epoxy (Panels lH1lA & lH1lB) failed while the SSPC-SP 2 cleaned equivalents had a rust grade of ten in both the repaired and over coated areas.

- One panel in the oil tolerant epoxy set (Panel 3VA) failed when applied over used diesel motor oil while the duplicate panel (3VB) was a rust grade eight with extensive rust blisters on the repair area and a rust grade ten on the recoat area. The rust was not removed prior to applying the contaminated motor oil.

- Both the duplicate panels coated with a moisture and oil tolerant epoxy applied over an oil-moisture combination had rust grade nine ratings over the repair area and a Rust Grade ten over the recoat area (Panel 4VA & 4VB).

- Disregarding the modified inorganic coating system that totally failed, the phosphoric acid treated panel series, and the oil contaminated panels, eleven of the twelve remaining failed panels had been “Power Tooled Cleaned to Bare Metal," SSPC-SP 11. Only one of the thirteen failed panels had been hand tooled cleaned (SSPC-SP 2). Two of the Formula 150 controls that failed had been applied

3.1.2.1 Three Year Atmospheric Exposure (Continued)

over a power tooled cleaned (SSPC-SP 11) surface.

. Of the coatings that had panels with both passed and failed repaired areas, only three of the thirteen had film thicknesses of 10 roils or less. Two of the three were formula 150 controls (Panels lK1lA & lK1lB) with film thicknesses of 7.5 and 8.5 roils, respectively. It should also be remembered that these two panels had been SSPC-SP 11 cleaned. The opposite was true for blistering where seven of the eight had dry film thickness of less than ten roils, the exception being an oil tolerant epoxy applied over a diesel motor oil contaminated rusty surface.

. With the exception of the two controls with film thicknesses below 10 which were applied over SSPC-SP 11 prepared surfaces (Panels lK1lA & lK1lB), the balance the controls demonstrated excellent performance-Five with rust grade ten and one with rust grade eight.

3.1.2.2 Sea Water Immersion (See Table 4)

. Three repair products performed well with a rust grade ten over both hand and power tool cleaning. Included were a 100% solids epoxy novolac (Panels 1H2 & lH1l), one of the amine adduct cured epoxies (Panels 1G2 & lG1l), a rust/moisture tolerant epoxy (Panels 1C2 & lC1l), and ten out of eleven of the Formula 150 controls. It is interesting to note, that all but one of these best performing products had a dry film thickness of 10.2 roils or greater in the repaired area. Two had a 20 roils or greater dry film thickness. This demonstrates the critical impact that film thickness has on the performance of barrier type coatings, particularly in an immersion environment. The amine adduct cured epoxy

3.1.2.2 Three Year Sea Water Immersion (Continued) .

performed well in the repaired area, but in the over coated formula 150 area, performance was marginal (rust grade seven).

. Six products performed satisfactorily over one of the alternate repair preparations but failed over the other surface preparation. Two of the failures occurred over SSPC-SP 11 and four over SSPC-SP 2 surface preparations. The six products were as follow with the failure surface preparation and panel number noted in parenthesis.

(a) Polyamide Epoxy (Panel 2A2-SSPC-SP 11)
(b) Zinc Rich Polyamide Epoxy Primer with Polyamide Epoxy Topcoat (Panel 1B2-SSPC-SP 2)
(c) Polyamide Surface Tolerant Epoxy (Panel lDll-SSPC-SP 11)
(d) Second Amine Adduct Cured Epoxy (Panel 2G2-SSPC-SP 2)
(e) Moisture Tolerant Epoxy (Panel 1V2-SSPC-SP 2)
(f) Moisture Cure Micaceous Iron Oxide Polyurethane with Formula 150 Topcoat (Panel 3W11-SSPC-SP 11)

. Five products failed over both alternate surface preparations. Included were three different moisture cure polyurethane formulations-two with Formula 150 topcoats, a modified inorganic (polysiloxane) , and a polyamide epoxy. Four of these products failed over one of the surface preparations after only one year immersion.

. One of the moisture cure micaceous iron oxide urethane panels top coated with the formula 150 epoxy (Panel 3w11) applied over a SSPC-SP 11 cleaned surface failed; whereas, the SSPC-SP 2 panel performed satisfactory, albeit with rust grade of less than 10. It should be

3.1.2.2 Three Year Sea Water Immersion (Continued)

noted that the coating thickness of the failed panel was 6.8 roils.

- The repair area controls using Formula 150 over three surface preparations SSPC-SP 2, SSPC-SP 10, and SSPC-SP 11 had a rust grade 10 which is excellent performance. One of the original steel stock controls with no prerusting, originally abrasive blasted to SSPC-SP 5, “White Blast Cleaning, had a rust grade of eight with eight-few (8F) blisters. Six of the nine prerusted Formula 150 control topcoated with Formula 150, i.e., top and bottom of each panel, after prerusting exposure and surface cleaning had a rust rating of seven or less. The poor performance was due to rusting of the overcoated areas. None was due to delamination or blistering of the top coat. Most of the candidate repair coatings performed better in the overcoat areas than did the Formula 150. Some of the coating systems failed in the repair area but had rust rating of nine or better in the overcoat area.

- All of the Formula 150 controls treated with phosphoric acid performed well in the repair area.

- Generally, the polyurethane systems, regardless of formulation, performed poorly in immersion which was predicted by most of the formulators.

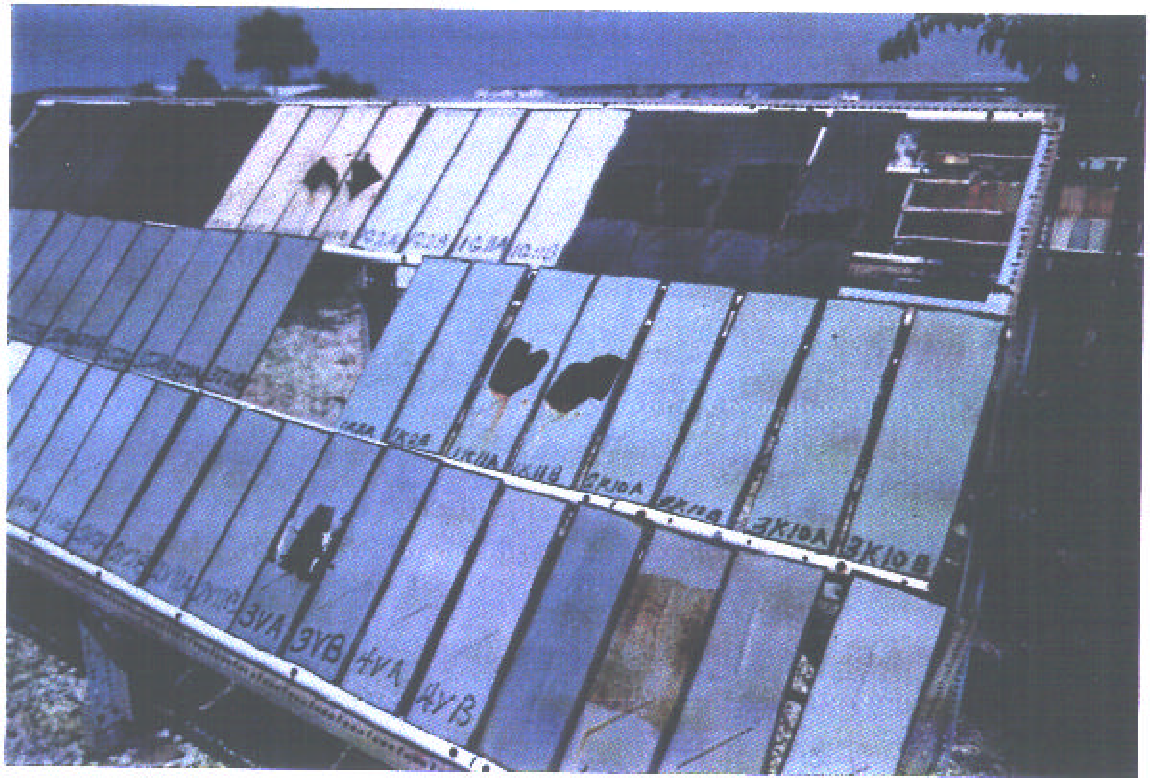

FIGURE 12: PANELS EXPOSED TO 45° SOUTH ON MARINE TEST FENCE

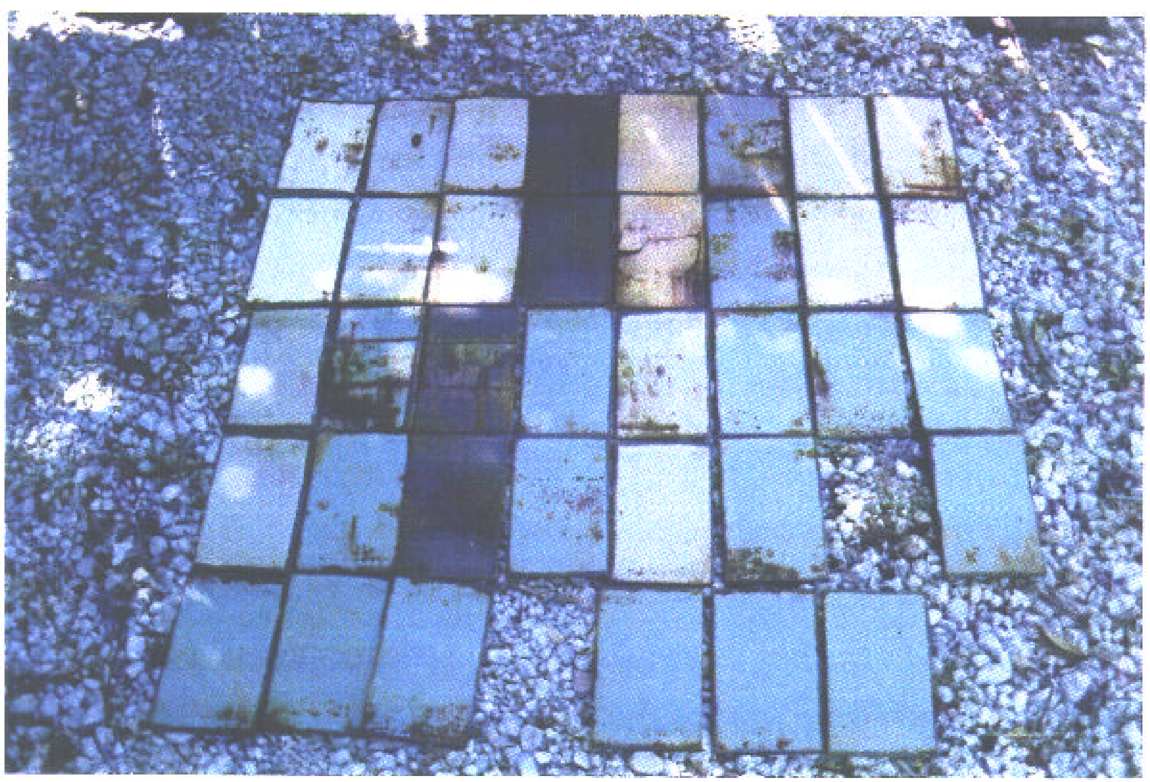

FIGURE 13: IMMERSION TEST PANELS LAID OUT READY FOR GRADING

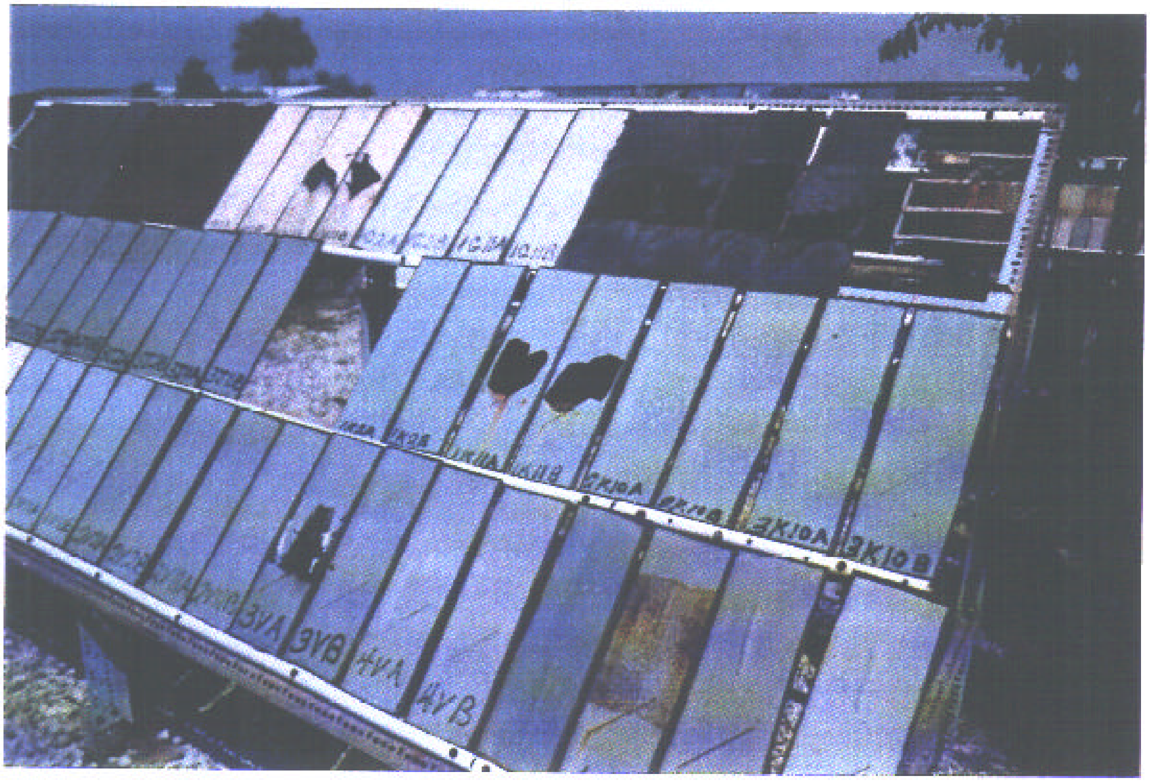

FIGURE 12: PANELS EXPOSED TO 45° SOUTH ON MARINE TEST FENCE

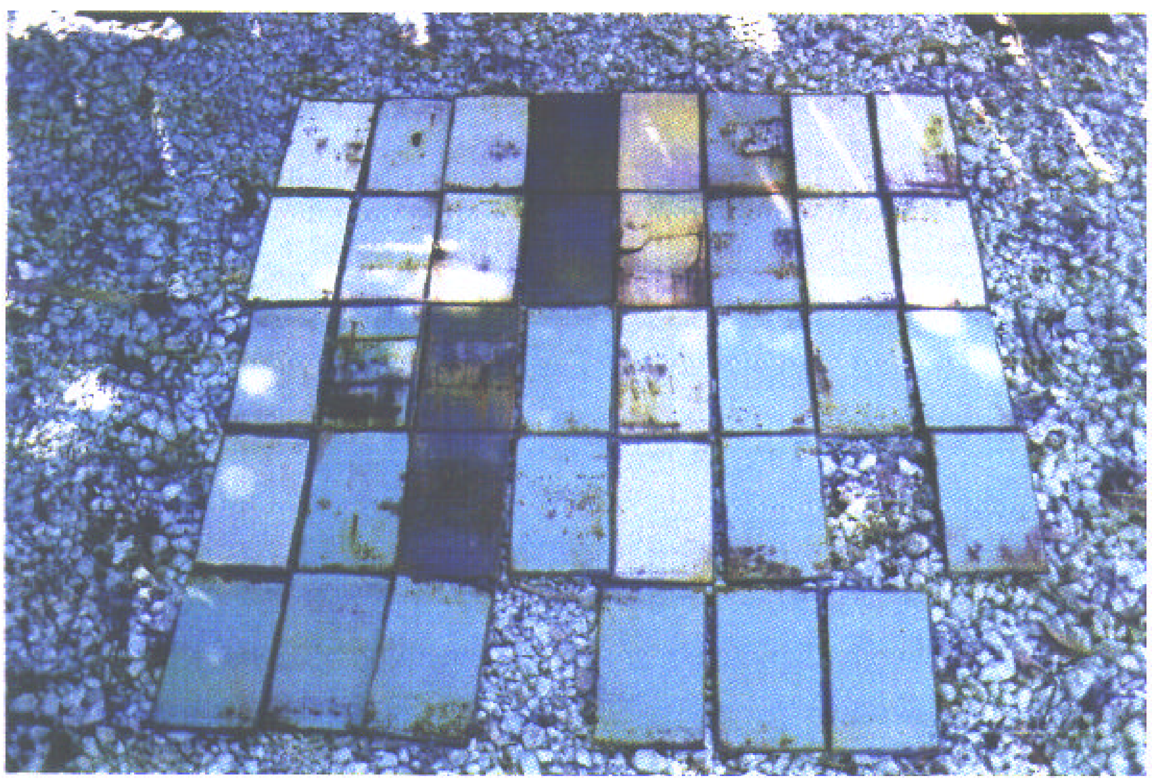

FIGURE 13: IMMERSION TEST PANELS LAID OUT READY FOR GRADING

TABLE 3-ATMOSPHERIC TEST RESULTS

ONE, TWO, AND THREE TEST RESULTS

PANEL NUMBER	MANUFACTURER	SURFACE PREPARATION	1ST COAT	1ST COAT DFT[1]	2ND COAT	TOTAL DFT[1]	ONE YEAR RESULTS[5]		TWO YEAR RESULTS[5]		THREE YEAR RESULTS[5]	
							REPAIR AREA	TOPCOAT AREA	REPAIR AREA	TOPCOAT AREA	REPAIR AREA	TOPCOAT AREA
1A2A	AMERON	SSPC-SP 2	149	8.4	149	10.3	10	Slight Checking Lower Panel	10 Rust Erosion	Wrinkle @ Bottom	10 rust Erosion	10 rust Erosion
1A2B	AMERON	SSPC-SP 2	149	5.9	149	7.2	8F Blisters 10 Rust	10	10 Rust Erosion	10	10 rust Erosion	10 rust Erosion
1A11A	AMERON	SSPC-SP 11	149	7.1	149	11.1	10	10	10	10	10 rust Erosion	10 rust Erosion
1A11B	AMERON	SSPC-SP 11	149	7.2	149	10.9	10	10	10	10	10 rust Erosion	10 rust Erosion
2A2A	AMERON	SSPC-SP 2	3207	3.8	2203	6.1	10	10	10	10	10	10
2A2B	AMERON	SSPC-SP 2	3207	3.8	2203	7.2	10	10	10	10	10	10
2A11A	AMERON	SSPC-SP 11	3207	3.2	2203	5.7	10	10	10	10	10	10
2A11B	AMERON	SSPC-SP 11	3207	5.2	2203	8.5	10	10	10	10	10	10
1B2A	CARBOLINE	SSPC-SP 2	858	10.6	890	13.9	10	10	10	10	10	10
1B2B	CARBOLINE	SSPC-SP 2	858	5.6	890	13.3	10	10	10	10	10	10
1B11A	CARBOLINE	SSPC-SP 11	858	5.8	890	10.7	10	10	10	10	10	10
1B11B	CARBOLINE	SSPC-SP 11	858	4.6	890	10.7	10	10	10	10	10	10
2B2A	CARBOLINE	SSPC-SP 2	890	7.3	890	10.5	10	10	10	10	10	10
2B2B	CARBOLINE	SSPC-SP 2	890	8.8	890	15.1	10	10	10	10	Cracking 10 Rust	10

TABLE 3-ATMOSPHERIC TEST RESULTS ONE, TWO, AND THREE TEST RESULTS												
PANEL NUMBER	MANUFACTURER	SURFACE PREPARATION	1ST COAT	1ST COAT DFT[1]	2ND COAT	TOTAL DFT[1]	ONE YEAR RESULTS[5]		TWO YEAR RESULTS[5]		THREE YEAR RESULTS[5]	
							REPAIR AREA	TOPCOAT AREA	REPAIR AREA	TOPCOAT AREA	REPAIR AREA	TOPCOAT AREA
2B11A	CARBOLINE	SSPC-SP 11	890	6.7	890	13.1	Cracking/Delamination 1" Back From Scribe	10	Failed	10	Failed	10
2B11B	CARBOLINE	SSPC-SP 11	890	5.0	890	11.8	Cracking/Delamination 1" Back From Scribe	10	Failed	10	Failed	10
1C2A	CORROLESS	SSPC-SP 2	EP	16.8	EP	17.9	10	10	10	10	10	10
1C2B	CORROLESS	SSPC-SP 2	EP	15.1	EP	21.2	10	10	10	10	10	10
1C11A	CORROLESS	SSPC-SP 11	EP	10.3	EP	11.3	10	10	10	10	10	10
1C11B	CORROLESS	SSPC-SP 11	EP	17.1	EP	18.3	10	10	10	10	10	10
2C2A	CORROLESS	SSPC-SP 2	SHB	5.1	SHB	7.7	10	10	8MD Blisters 10 Rust	10	Rust Blisters But Not Ruptured	10
2C2B	CORROLESS	SSPC-SP 2	SHB	4.6	SHB	7.5	10	10	8MD Blisters 10 Rust	10	Rust Blister W/One Rupture	10
2C11A	CORROLESS	SSPC-SP 11	SHB	4.0	SHB	6.1	10	10	10	10	Failed	10
2C11B	CORROLESS	SSPC-SP 11	SHB	2.6	SHB	5.1	10	10	10	10	Rust Blisters But Not Ruptured	10

TABLE 3-ATMOSPHERIC TEST RESULTS

ONE, TWO, AND THREE TEST RESULTS

PANEL NUMBER	MANUFACTURER	SURFACE PREPARATION	1ST COAT	1ST COAT DFT[1]	2ND COAT	TOTAL DFT[1]	ONE YEAR RESULTS[5]		TWO YEAR RESULTS[5]		THREE YEAR RESULTS[5]	
							REPAIR AREA	TOPCOAT AREA	REPAIR AREA	TOPCOAT AREA	REPAIR AREA	TOPCOAT AREA
1D2A	DEVOE	SSPC-SP 2	236	9.5	236	15.1	10	10	.25" Undercut @ Scribe	10	10 Rust Erosion	10 Rust Erosion
1D2B	DEVOE	SSPC-SP 2	236	11.9	236	14.8	10	10	.063" Undercut @ Scribe	10	10 Rust Erosion	10 Rust Erosion
1D11A	DEVOE	SSPC-SP 11	236	12.8	236	16.1	Undercut Delamination From Scribe	10	Failed	10	Failed	10 Rust Erosion
1D11B	DEVOE	SSPC-SP 11	236	10.4	236	11.0	Undercut Delamination From Scribe	10	Failed	10	Failed	10 Rust Erosion
1G2A	INTERNATIONAL	SSPC-SP 2	KHA062	7.3	KHA062	12.5	10	10	10	10	10 Rust Erosion	10 Rust Erosion
1G2B	INTERNATIONAL	SSPC-SP 2	KHA062	9.1	KHA062	14.9	10	10	10	10	10 Rust Erosion	10 Rust Erosion
1G11A	INTERNATIONAL	SSPC-SP 11	KHA062	8.6	KHA062	12.1	10	10	10	10	10 Rust Erosion	10 Rust Erosion
1G11B	INTERNATIONAL	SSPC-SP 11	KHA062	8.9	KHA062	13.7	10	10	10	10	10 Rust Erosion	10 Rust Erosion
2G2A	AMERON	SSPC-SP 2	738	11.4	738	19.8	Delamination	10	Failed	10	Failed	10

TABLE 3-ATMOSPHERIC TEST RESULTS

ONE, TWO, AND THREE TEST RESULTS

PANEL NUMBER	MANUFACTURER	SURFACE PREPARATION	1ST COAT	1ST COAT DFT[1]	2ND COAT	TOTAL DFT[1]	ONE YEAR RESULTS[5]		TWO YEAR RESULTS[5]		THREE YEAR RESULTS[5]	
							REPAIR AREA	TOPCOAT AREA	REPAIR AREA	TOPCOAT AREA	REPAIR AREA	TOPCOAT AREA
2G2B	AMERON	SSPC-SP 2	738	9.0	738	14.4	Delamination	10	Failed	10	Failed	10
2G11A	AMERON	SSPC-SP 11	738	12.5	738	22.8	Delamination	10	Failed	10	Failed	10
2G11B	AMERON	SSPC-SP 11	738	9.7	738	18.9	Delamination	10	Failed	10	Failed	10
1H2A	NSP	SSPC-SP 2	120	16.8	120	24.2	10	10	10	10	10	10
1H2B	NSP	SSPC-SP 2	120	14.2	120	15.9	10	10	10	10	10	10
1H11A	NSP	SSPC-SP 11	120	12.0	120	16.8	10	10	Failed	10	Failed	10
1H11B	NSP	SSPC-SP 11	120	12.2	120	14.0	10	10	Failed	10	Failed	10
1V2A	MILES	SSPC-SP 2	2225	4.0	291-39	4.9	10	10	8D Blisters 10 Rust	10	Extensive Rust Blisters 6 Rust	10
1V2B	MILES	SSPC-SP 2	2225	3.4	291-39	4.6	10	10	8MD Blisters 10 Rust	10	8 With Rust Blisters	10
1V11A	MILES	SSPC-SP 11	2225	2.5	291-39	4.3	10	10	8F Blisters 10 Rust	10	8 With Rust Blisters	10
1V11B	MILES	SSPC-SP 11	2225	3.1	291-39	4.5	10	10	8F Blisters 10 Rust	10	8 With Rust Blisters	10
2V2A	VALSPAR	SSPC-SP 2	600	8.8	600	13.1	10	10	10	10	10	10

TABLE 3-ATMOSPHERIC TEST RESULTS

ONE, TWO, AND THREE TEST RESULTS

PANEL NUMBER	MANUFACTURER	SURFACE PREPARATION	1ST COAT	1ST COAT DFT[1]	2ND COAT	TOTAL DFT[1]	ONE YEAR RESULTS[5]		TWO YEAR RESULTS[5]		THREE YEAR RESULTS[5]	
							REPAIR AREA	TOPCOAT AREA	REPAIR AREA	TOPCOAT AREA	REPAIR AREA	TOPCOAT AREA
2V2B	VALSPAR	SSPC-SP 2	600	7.8	600	14.3	10	10	10	10	10	10
2V11A	VALSPAR	SSPC-SP 11	600	9.0	600	10.1	10	10	10	10	10	10
2V11B	VALSPAR	SSPC-SP 11	600	9.4	600	16.0	10	10	10	10	10	10
3VA	VALSPAR	NONE-Oil Contaminate	500AL	12.2	NONE		Delamination	10	Failed	10	Failed	10
3VB	VALSPAR	NONE-Oil Contaminate	500AL	10.5	NONE		Delamination	10	4MD Blisters 8 Rust	10	8 Rust With Extensive Rust Blisters	10
4VA	VALSPAR	NONE-Oil & Moisture Contaminate	600	13.8	NONE		10	10	10	10	Checking 9 Rust	10
4VB	VALSPAR	NONE- Oil & Moisture Contaminate	600	10.8	NONE		10	10	10	10	Minor Checking 9 Rust	10
1J2A	WASSER	SSPC-SP 2	MCZINC	4.0	MCMICRO	10.8	10	10	10	10	10	10
1J2B	WASSER	SSPC-SP 2	MCZINC	5.2	MCMICRO	10.8	10	10	10	10	10	10
1J11A	WASSER	SSPC-SP 11	MCZINC	3.0	MCMICRO	6.5	10	10	10	10	10	10
1J11B	WASSER	SSPC-SP 11	MCZINC	3.0	MCMICRO	7.2	10	10	10	10	10	10
2J2A	WASSER	SSPC-SP 2	MCMICRO	4.4	MCMICRO	10.7	9	10	9	10	8	10
2J2B	WASSER	SSPC-SP 2	MCMICRO	5.7	MCMICRO	9.2	10	10	9	10	8	9

TABLE 3-ATMOSPHERIC TEST RESULTS

ONE, TWO, AND THREE TEST RESULTS

PANEL NUMBER	MANUFACTURER	SURFACE PREPARATION	1ST COAT	1ST COAT DFT[1]	2ND COAT	TOTAL DFT[1]	ONE YEAR RESULTS[5]		TWO YEAR RESULTS[5]		THREE YEAR RESULTS[5]	
							REPAIR AREA	TOPCOAT AREA	REPAIR AREA	TOPCOAT AREA	REPAIR AREA	TOPCOAT AREA
2J11A	WASSER	SSPC-SP 11	MCMICRO	3.1	MCMICRO	6.2	9	10	8	10	7	10
2J11B	WASSER	SSPC-SP 11	MCMICRO	3.5	MCMICRO	7.2	10	10	9	10	8	10
3J2A	WASSER	SSPC-SP 2	MCTAR	5.1	MCMICRO	9.7	10	10	10	10	10 Rust Erosion	10
3J2B	WASSER	SSPC-SP 2	MCTAR	4.1	MCMICRO	9.4	10	10	10	10	10 Rust Erosion	10
3J11A	WASSER	SSPC-SP 11	MCTAR	3.0	MCMICRO	6.5	10	10	10	10	10 Rust Erosion	10
3J11B	WASSER	SSPC-SP 11	MCTAR	4.3	MCMICRO	8.5	10	10	10	10	10 Rust Erosion	10
1K2A	FORMULA 150	SSPC-SP 2	CONTROL	4.6	CONTROL	12.3	10	10	10	10	10	10
1K2B	FORMULA 150	SSPC-SP 2	CONTROL	6.8	CONTROL	9.2	10	10	10	10	8	10
1K11A	FORMULA 150	SSPC-SP 11	CONTROL	4.1	CONTROL	7.5	Delamination	10	Failed	10	Failed	10
1K11B	FORMULA 150	SSPC-SP 11	CONTROL	3.0	CONTROL	8.5	Delamination	10	Failed	10	Failed	10
2K10A	FORMULA 150	SSPC-SP 10	CONTROL	3.0	CONTROL	7.9	10	10	10	10	10	10
2K10B	FORMULA 150	SSPC-SP 10	CONTROL	3.7	CONTROL	10.4	10	10	10	10	10	10
3K10A	FORMULA 150	SSPC-SP 10	CONTROL	12.0	CONTROL	14.5	10	10	10	10	10	10
3K10B	FORMULA 150	SSPC-SP 10	CONTROL	10.4	CONTROL	13.5	10	10	10	10	10	10

TABLE 3-ATMOSPHERIC TEST RESULTS

ONE, TWO, AND THREE TEST RESULTS

PANEL NUMBER	MANUFACTURER	SURFACE PREPARATION	[illegible]	1ST COAT DFT[1]	2ND COAT	TOTAL DFT[1]	ONE YEAR RESULTS[3]		TWO YEAR RESULTS[3]		THREE YEAR RESULTS[3]	
							REPAIR AREA	TOPCOAT AREA	REPAIR AREA	TOPCOAT AREA	REPAIR AREA	TOPCOAT AREA
1N8		SSPC-SP 2[2]	149	[illegible]	149	9.7	8 Few Blisters Around Scribe	10	8D Blister 8 Rust	10 Rust Erosion	6 Rust Erosion	10 Rust Erosion
1N9	AMERON	SSPC-SP 2[2]	149	7.0	149	[illegible]	8 Few Blisters Around Scribe	[illegible]	6D Blisters 6 Rust	10 Rust Erosion	6 Rust Erosion	10 Rust Erosion
1N10	AMERON	SSPC-SP 11[2]	149	8.	[illegible]	[illegible]	[illegible]	[illegible]	0	10 Rust Erosion	10 Rust Erosion	10 Rust Erosion
1N1'		SSPC-SP [2]	149	4.8	149	[illegible]	[illegible]	[illegible]	10	10 Rust Erosion	10 Rust Erosion	10 Rust Erosion
1N12		NOTE[2]	149		149	9.1	Failed	[illegible]	Fa led	10 Rust Erosion	4 Rust Erosion	10 Rust Erosion
1N13	AMERON	NOTE[2]	149			[illegible]	Failed	10	Fa ed	10 Rust Erosion	Fa ed	10 Rust Erosion
101	WASSER	SSPC-SP 11	MCMICRO	N/R		N/R	Failed	10	Failed	N/A	Failed	10 Rust Erosion
[illegible]	WASSER	SSPC-SP	MCMICRO	N/R		N/R	[illegible]	[illegible]	[illegible]	N/A	8 Rust Around Weld	8 Top 10 Bottom
120	WASSER	SSPC-SP 1	291-39	N/R		N/R	9	10	10	N/A	8	10
121	MILES	SSPC-SP 2	MC-ZINC	N\R		N/R	10	10	10	N/A	10	10

TABLE 4-BALLAST TANK TEST RESULTS

ONE, TWO AND THREE YEAR TEST RESULTS

PANEL NUMBER	MANUFACTURER	SURFACE PREPARATION	1ST COAT	1ST COAT DFT[1]	2ND COAT	TOTAL DFT[1]	ONE YEAR TEST RESULTS[5]		TWO YEAR TEST RESULTS[5]		THREE YEAR TEST RESULTS[5]	
							REPAIR AREA	TOPCOAT AREA	REPAIR AREA	TOPCOAT AREA	REPAIR AREA	TOPCOAT ARE
1A2	AMERON	SSPC-SP 2	738	10.0	738	21.7	8	10	Failed	10	Failed	10
1A11	AMERON	SSPC-SP 11	738	10.4	738	26.7	Failed	10	Failed	10	Failed	10
2A2	AMERON	SSPC-SP 2	385P	6.3	385	7.9	8	9	6 Few Blisters Probably Underfilm Corrosion	9	Ruptured Blister 6 Rust	8
2A11	AMERON	SSPC-SP 11	385P	5.0	385	8.3	10	10	10	9	10	9
1B2	CARBOLINE	SSPC-SP 2	858	9.9	890	10.1	10	Pinholes with Rust	10	7	Failed	6
1B11	CARBOLINE	SSPC-SP 11	858	5.2	890	8.4	10	10	10	8	Lower Feathered Edge Overlap Failed. 8 Rust Balance	8
2B2	CARBOLINE	SSPC-SP 2	890	8.6	890	12.6	10	10	9	9	Failed	9
2B11	CARBOLINE	SSPC-SP 11	890	6.0	890	8.5	10	10	9	8	Failed	6 Top 8 Bottom
1C2	CORROLESS	SSPC-SP 2	EP	21.2	EP	24.1	10	10	10	10	2M Blisters 10 Rust	9
1C11	CORROLESS	SSPC-SP 11	EP	16.6	EP	19.4	10	10	10	10	10	9
1D2	DEVOE	SSPC-SP 2	236	11.7	236	14.9	10	10	10	10	10	9
1D11	DEVOE	SSPC-SP 11	236	9.1	236	17.9	Delamination of Topcoat	10	Total Delamination	10	Failed	9

TABLE 4-BALLAST TANK TEST RESULTS

ONE, TWO AND THREE YEAR TEST RESULTS

PANEL NUMBER	MANUFACTURER	SURFACE PREPARATION	1ST COAT	1ST COAT DFT[1]	2ND COAT	TOTAL DFT[1]	ONE YEAR TEST RESULTS[5]		TWO YEAR TEST RESULTS[5]		THREE YEAR TEST RESULTS[5]	
							REPAIR AREA	TOPCOAT AREA	REPAIR AREA	TOPCOAT AREA	REPAIR AREA	TOPCOAT ARE
1F2	MILES	SSPC-SP 2	2225	N/R	291-39	8.4	6	8	4 Few Blisters 6 Rust	8 Few Blisters 10 Rust	Failed	6
1F11	MILES	SSPC-SP 11	2225	N/R	291-39	4.5	9	10 with Alligatoring	Edges are Failing	Checking 8MD Blisters 7 Rust	Failed	6
1G2	INTERNATIONAL	SSPC-SP 2	KHA062	13.2	KHA062	18.6	10	9	10	9	Pinholes 10 Rust	10 Top 7 Bottom
1G11	INTERNATIONAL	SSPC-SP 11	KHA062	7.9	KHA062	12.3	10	8	10	8	Pinholes 10 Rust	7 Top 8 Bottom
2G2	INTERNATIONAL	SSPC-SP 2	FPA327	6.7	FPA327	10.8	9 Rust w/one Blister	8	Large Delamination 33% of Area	8 Top 6 Bottom	Failed	9 Top 4 Bottom
2G11	INTERNATIONAL	SSPC-SP 11	FPA327	4.0	FPA327	7.6	10	8	10	6 Top 7 Bottom	Pinholes 10 Rust	6 Top 8 Bottom
1H2	NSP	SSPC-SP 2	120	15.7	120	16.7	10	10	10	8	10	8
1H11	NSP	SSPC-SP 11	120	18.1	120	17.2	10	10	10	9	10	9
1W2	WASSER	SSPC-SP 2	MCZINC	3.9	150	7.7	Underfilm Corrosion	8	Failed	Top-8MD Blister/9 Bottom-6 Ruptured Blister	Failed	8 Top Failed Bottom
1W11	WASSER	SSPC-SP 11	MCZINC	2.5	150	6.6	8	9	8	10 Top 7 Bottom	6	9 Top 7 Bottom
2W2	WASSER	SSPC-SP 2	MCTAR	7.3	MCTAR	8.2	6	10	Failed	10	Failed	8 Top 7 Bottom

TABLE 4-BALLAST TANK TEST RESULTS

ONE, TWO AND THREE YEAR TEST RESULTS

PANEL NUMBER	MANUFACTURER	SURFACE PREPARATION	1ST COAT	1ST COAT DFT[1]	2ND COAT	TOTAL DFT[1]	ONE YEAR TEST RESULTS[5]		TWO YEAR TEST RESULTS[5]		THREE YEAR TEST RESULTS[5]	
							REPAIR AREA	TOPCOAT AREA	REPAIR AREA	TOPCOAT AREA	REPAIR AREA	TOPCOAT AREA
2W11	WASSER	SSPC-SP 11	MCTAR	4.4	MCTAR	7.1	10	10	8	10 Top 8 Bottom	6	9 Top 8 Bottom
3W2	WASSER	SSPC-SP 2	MCMICRO	6.7	150	9.3	10	10	10	9 Top 8 Bottom	9	8 Top 7 Bottom
3W11	WASSER	SSPC-SP 11	MCMICRO	3.4	150	6.8	6	8	6D Blisters 6 Rust	8 Top 9 Bottom	4	7 Top 9 Bottom
1V2	VALSPAR	SSPC-SP 2	600	N/R	600	18.2	10	10	7	10 Top 6 Bottom	4	10 Top 4 Bottom
1V11	VALSPAR	SSPC-SP 11	600	N/R	600	18.9	10	10	10	10 Top 8 Bottom	9	9 Top 7 Bottom
1K2	CONTROL	SSPC-SP 2	150	8.9	150	11.7	10	9	10	9 Top 7 Bottom	10	8 Top 7 Bottom
1K11	CONTROL	SSPC-SP 11	150	7.8	150	10.2	10	8	10	8 Top 6 Bottom	10	7 Top 4 Bottom
2K10	CONTROL	SSPC-SP 10	150	6.7	150	8.2	10	8	9	10 Top 6 Bottom	Edge Failure 10 Rust	9 Top 4 Bottom
4K10A	CONTROL	SSPC-SP 10	150	16.6	150	20.4	N/A	10	N/A	10	N/A	10
4K10B	CONTROL	SSPC-SP 10	150	8.2	150	11.0	N/A	10	N/A	8	N/A	8F Blisters 8 Rust
1N1	CONTROL	SSPC-SP 2[2]	150	10.3	150	12.2	10	8	10	8 Top 7 Bottom	10	6
1N2	CONTROL	SSPC-SP 2[2]	150	10.5	150	13.3	10	8	10	8 Top 7 Bottom	10	8 Top 6 Bottom
1N3	CONTROL	NAVAL JELLY	150	9.1	150	11.2	10	6	10	8 Top 6 Bottom	10	6 Top 4 Bottom

TABLE 4-BALLAST TANK TEST RESULTS

ONE, TWO AND THREE YEAR TEST RESULTS

PANEL NUMBER	MANUFACTURER	SURFACE PREPARATION	1ST COAT	1ST COAT DFT[1]	2ND COAT	TOTAL DFT[1]	ONE YEAR TEST RESULTS[5]		TWO YEAR TEST RESULTS[5]		THREE YEAR TEST RESULTS[5]	
							REPAIR AREA	TOPCOAT AREA	REPAIR AREA	TOPCOAT AREA	REPAIR AREA	TOPCOAT AREA
1N5	CONTROL	SSPC-SP 11[2]	150	6.8	150	20.1	10	8	10	8 Top 7 Bottom	10	6
1N6	CONTROL	SSPC-SP 11[2]	150	8.4	150	10.2	10	9	10	9 Top 8 Bottom	10	Edge Failure 10 Top 8 Bottom
1N7	CONTROL	SSPC-SP 11[2]	150	9.0	150	11.6	10	10	10	10 Top 9 Bottom	10	9 Top 8 Bottom

NOTES:

1. The recorded Dry Film Thickness (DFT) is for the center bare area on(y. The balance of the panel is primed with Formula 150. The OFT of the Formula 150 ranges from 4 6 roils. The final coat is applied over both the Formula 150 and the test primer.

2. Naval Jelly is a proprietary phosphoric acid conversion coating which was applied as noted in the "surface Preparation" column.

3. The Formula 150 is Hil-P-24441, Type 1 supplied by Devoa Paint.

4. Panels were initially primed with Formula 150. The center section of each panel was left bare. The primed panels were placed in a simuated ballast tank. The panels whi were to be exposed on the exterior exposure rack were removed after 30 days and then al lowed to age an additional 30 days atmospherically. The ballast last tank test seri remained in the bal`last tank for 60 days. The center corroded areas were then cleaned as noted in the tables.

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